APPENDIX I

Selenium Management Strategies

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Selenium Management Strategies

I.1 INTRODUCTION

I.1.1 Purpose and Need

The Salton Sea Species Conservation Habitat Project (SCH Project), proposed by the California Natural Resources Agency, would create up to approximately 2,080 to 3,770 acres of shallow ponds at the Salton Sea's edge (final acreage would depend on the alternative selected and funds available for construction). The ponds would be designed to provide appropriate foraging habitat for piscivorous (fish-eating) birds that depend on the Salton Sea.

Selenium is a naturally occurring element and an essential nutrient. However, when it is present at elevated concentrations in the food web, selenium can cause adverse effects, especially on reproduction of birds and fish. Selenium is already present in the water, sediments, and biota of the Salton Sea ecosystem (DWR and DFG 2007). The question is whether the SCH Project would increase the probability and magnitude of selenium impacts relative to existing and expected future conditions. Thus, it is necessary to evaluate the potential selenium exposure and risks to ecological receptors (primarily aquatic and benthic invertebrates, fish, and birds) and to develop appropriate measures to avoid, reduce, and mitigate potential impacts.

The purpose of this report is to:

- Evaluate the scope of the selenium problem for the proposed SCH Project;
- Identify a range of potential management strategies for the SCH Project's design and initial operations to minimize potential ecological impacts; and
- Outline a monitoring framework that would support adaptive management of SCH Project once operational.

I.1.2 Approach

The SCH Project is using the following approach to evaluate selenium risk and develop management strategies:

- Evaluate the scope of the selenium problem;
- Characterize sources and concentrations of selenium at the Project area under existing conditions and proposed operations;
- Identify potential ecological receptors likely to be affected (i.e., species using the SCH ponds) and target goals;
- Understand pathways to receptors, given the proposed design and operations;
- Estimate the probability, severity, and extent of potential risks from Project implementation;
- Identify a range of potential management strategies;
- Identify source control and mitigation strategies to minimize exposure of ecological receptors; and

- Identify treatment strategies if applicable and feasible (only if source control and mitigation strategies are not sufficient).

Information and insights for selenium evaluation and management were obtained from various sources. Background information and initial screening-level analysis of selenium risk came from the *Salton Sea Ecosystem Restoration Program Final Programmatic Environmental Impact Report* (DWR and DFG 2007), in particular *Appendix F – Ecological Risk Assessment*. The Bureau of Reclamation (Reclamation) measured water quality of Salton Sea and influent rivers quarterly in 2004–2009 (C. Holdren, Reclamation, unpublished data). The U.S. Geological Survey (USGS) conducted studies of selenium bioaccumulation at the experimental Saline Habitat Ponds (SHP) complex (Miles et al. 2009) and agricultural drains at the Sea's southern end (Saiki et al. 2010). University of California Riverside (UCR) conducted site-specific sampling in 2010 at alternative SCH Project sites (Amrhein et al. 2010) and ecological risk modeling of receptors, pathways, and bioaccumulation potential (Sickman et al. 2011). Potential water treatment technologies were reviewed for their effectiveness, feasibility, and applicability to the SCH Project (Cardno ENTRIX 2010). Finally, a science panel[1] reviewed the selenium ecological risk modeling data and provided input on strategies for source control, mitigation, and treatment.

I.1.3 Regulatory Standards and Toxicity Thresholds

Water quality guidelines for selenium in the Salton Sea Basin are 5 micrograms per liter[2] (µg/L) for chronic exposure and 20 µg/L for acute (1-hour average) exposure (Colorado River Basin Regional Water Quality Control Board 2006). For sediment, the United States Department of the Interior (1998) and Hamilton (2004) classified selenium concentrations between 1 and 4 micrograms per gram (µg/g) (or milligrams per kilogram [mg/kg]) as "elevated above background" or "level of concern," and concentrations >4 µg/g as the "toxicity threshold."

Selenium concentrations in biota considered to pose a potential toxicity risk vary depending on species and studies (Amrhein and Smith 2011; Ohlendorf and Heinz 2011). Lemly (2002) considered the effect of bioaccumulation within a food chain and recommended somewhat lower selenium thresholds of 2 µg/L of inorganic selenium in water, 2 µg/g in sediments, and 3 µg/g dry weight (dw) in food-chain organisms such as invertebrates. To avoid toxic effects on sensitive fish species, Lemly (2002) recommended a threshold of 4 µg/g dw in whole fish. Available evidence from the Salton Sea area indicates that tilapia, poeciliids (mosquitofish and mollies) and desert pupfish are not likely to be seriously affected at tissue concentrations of 4 µg/g dw (Saiki et al. 2010). For bird eggs, which may exhibit reduced hatching success or embryo deformities (teratogenesis) from selenium exposure, a conservative and widely reported toxicity reference value is 6 µg/g dw, although selenium sensitivity can vary widely depending on species and the chemical form of selenium in the diet (Ohlendorf and Heinz 2011).

[1] The panel convened on September 21, 2010, included scientists and resource managers with expertise in selenium environmental toxicology, geochemistry, treatment, and Salton Sea issues. Panel members included Chris Amrhein (UCR), Doug Barnum (USGS Salton Sea Science Office), Rick Gersberg (San Diego State University), Chris Holdren (Reclamation), Chen Huang (University of California Berkeley [UCB]), Keith Miles (USGS), Harry Ohlendorf (CH2M Hill), Theresa Presser (USGS), Carol Roberts (U.S. Fish and Wildlife Service [USFWS]), Mike Saiki (USGS), James Sickman (UCR), Joe Skorupa (USFWS), and Norman Terry (UCB).

[2] Concentrations of selenium can be expressed in various ways. Water concentrations are typically expressed as µg/L, or sometimes as parts per billion. Sediment concentrations can be expressed as either µg/g or mg/kg. Concentrations in biota are expressed as µg/g, or sometimes parts per million. Sediment and biota samples are typically dried before measuring, and concentrations are reported as µg/g dw.

I.2 SELENIUM SOURCES

Selenium is present in the water, sediments, and biota of the Salton Sea ecosystem (DWR and DFG 2007). Most of the selenium originally comes from the upper Colorado River in irrigation water used in the Imperial and Coachella valleys. Irrigation of seleniferous soils can also dissolve and transport selenium to drains (Ohlendorf 2003, as cited in DWR and DFG 2007). Selenium becomes concentrated by agricultural usage and is discharged from subsurface tile drains into surface drains that flow into the Sea either directly or via tributaries (Saiki et al. 2010).

I.2.1 Selenium Cycling

The biogeochemistry of selenium in aquatic systems is complex and controlled by several factors. Both the biotic and abiotic activity of selenium depends on its physiochemical form or species. Selenium chemistry resembles that of sulfur (Masscheleyn and Patrick 1993). Selenium, like sulfur, can exist in four different oxidation states: selenide (Se -II), elemental selenium (Se 0), selenite (Se IV or SeO_3^{2-}), and selenate (Se VI or SeO_4^{2-}) (Robberecht and Van Grieken 1982). Alterations in the oxidation state of selenium greatly affect solubility and play a major role in mobility, transport, fate, and effects of selenium species in wetland environments (Masscheleyn and Patrick 1993; Lemly 2002).

Inorganic forms of selenium (selenate and selenite) usually predominate in water, but inorganic as well as organic forms of selenium occur in water, sediment, and biological tissues. In an aquatic system, most selenium is associated with sediments (acting as a sink and reservoir) or plants and animals. In bottom sediments, metal and organic selenides are most common (Hamilton 2004). In water, selenate is reduced to selenite and both forms are removed from the aqueous phase into sediment. Once in sediment, selenite is reduced to elemental selenium, which may make up 99 percent of the selenium found in sediments.

Various biological, chemical, and physical processes can move selenium into or out of sediments; therefore, sediments may serve as only a temporary repository for selenium (Masscheleyn and Patrick 1993). Transport and partitioning of selenium in soils is highly influenced by pH (measure of the acidity or alkalinity of a substance) and Eh (oxidation/reduction conditions). Elemental selenium is essentially insoluble and stable in soils when anaerobic conditions occur. Heavy metal selenides and selenium sulfides are insoluble and will remain in soils with low pH or high organic matter (Kabata-Pendias 2001, as cited in DWR and DFG 2007). In contrast, selenates are very mobile and easily taken up by plants or leached through the soil due to their high solubility and low adsorption potential (onto soil particles). Selenates dominate in alkaline, well-oxidized soil environments and some (e.g., sodium selenate and potassium selenate) dominate in neutral, well-drained, mineral soils. While soluble selenates are responsible for the naturally occurring accumulation of high levels of selenium by plants, much of the total selenium measured in soils may be present in other forms. Under alkaline and oxidizing conditions, plants can accumulate the soluble forms of selenium, although selenate seems to be the preferred form for uptake (DWR and DFG 2007).

After selenium enters the sediment, further chemical and microbial reduction may occur, resulting in insoluble organic, mineral, elemental, or adsorbed selenium (Lemly 2002). Microscopic planktonic organisms, such as bacteria, protozoa, phytoplankton, and zooplankton, are a major component of the particulate matter in the water column. The particulate matter, in turn, forms the basis for detrital materials that settle onto the sediment and become the food source for sediment organisms, such as benthic macroinvertebrates. In addition, waterborne selenite can be physically adsorbed onto the sediment particles, ingested, absorbed, and transformed by the sediment organisms. Sediment-bound selenite can be reduced to insoluble elemental selenium by anaerobic microbial activities. Elemental selenium can be reduced further to inorganic and organic selenides and/or reoxidized to selenite and selenate by microorganisms in the sediment and/or in the digestive tracts of sediment macroinvertebrates. Selenides can enter the food chain via uptake into sediment organisms or be oxidized to selenite and selenate.

Selenium of different oxidation states can be further biotransformed by sediment organisms and transferred up the food chain (Fan et al. 2002; Hamilton 2004). Over time, most of the selenium associated with plant and animal tissues is deposited as detritus and eventually incorporated into the sediments. Some selenium forms may be volatilized to the atmosphere through microbial activity in the water and sediments or through direct release by aquatic plants (Lemly 2002).

Speciation affects transformation from dissolved forms to living organisms (e.g., algae, microbes) and nonliving particulate material at the base of the food webs. Selenate in the water column is taken up only slowly, especially if competition with sulfate (SO_4^{2-}) is involved. Selenite and organoselenides are much more reactive. When any form of selenium is taken up at the base of the food web by plants and microbes, it is converted to organoselenide. With extended residence times in a system the result is a buildup of proportionately more organoselenides and selenite as selenium is recycled through the base of food webs. In general, selenium concentrations in algae, microbes, sediments, or suspended particulates are 100 to 500 times higher than dissolved concentrations in selenate-dominated environments such as streams and rivers. However, when selenite or organoselenide are proportionately more abundant, the ratio can be 1,000 to10,000, such as in wetlands (Luoma and Presser 2009).

Wetting and drying cycles, as normally found in wetlands, are important factors that contribute to selenium mobilization and potential toxicity. Diffusive flux between water and sediments, in general, is highly influenced by the chemistry of both water and sediment (e.g., oxygen and selenium concentrations) (Byron and Ohlendorf 2007). Selenium is often present in chemically reduced forms when wetlands are submerged and have high organic matter. This condition favors volatilization (Masscheleyn and Patrick 1993, as cited in DWR and DFG 2007). When water levels decline and sediments are exposed, as seen with the exposed playa along the receding shoreline of the Salton Sea, selenium becomes more oxidized and bioavailable. As a result, the initial wetting as the SCH ponds are first filled has the potential to increase selenium bioavailability in sediments and organic matter (DWR and DFG 2007; Amrhein et al. 2011).

I.2.2 Selenium in Water

The Salton Sea receives flow from three rivers (Alamo, New, and Whitewater rivers), agricultural drainages, and ephemeral desert creeks. Reclamation has monitored seasonal water quality in the Salton Sea and its tributaries in 1999 and 2004–2009 (C. Holdren, Reclamation, unpublished data). Average waterborne concentrations of total selenium vary depending on water body (Table I-1). The Salton Sea has the lowest levels (mean 1.16 µg/L) because the deeper areas function as a sink for selenium (DWR and DFG 2007). For the period 2004–2009, mean annual total selenium concentrations in the rivers averaged 2.23 µg/L in the Whitewater River, 3.18 µg/L in the New River, and 5.09 µg/L in the Alamo River (C. Holdren, Reclamation, unpublished data). Summer 2010 sampling near the Project alternative sites found selenium concentrations of 1.2 µg/L in the Salton Sea, 4.1 µg/L in the Alamo River, and 1.8 µg/L in the New River (Amrhein and Smith 2011). By 2075, concentrations of selenium in New and Alamo rivers would not likely exceed 10 µg/L, as modeled in the Programmatic Environmental Impact Report (DWR and DFG 2007, Appendix H2).

Selenium concentrations in agricultural drains vary widely and are often higher. In 2005–2009, USGS measured total selenium in 29 drains or ponds operated by the Imperial Irrigation District (IID) along the Salton Sea's southern border (Saiki et al. 2010). Total selenium in unfiltered samples averaged 4.18 µg/L (range 0.79 to 79.1 µg/L). Total selenium concentrations in water were directly correlated with salinity and inversely correlated with total suspended solids concentrations. The total selenium in a subset of samples (n=7 drains, range 0.70 to 32.8 µg/L) was partitioned into the various selenium species. The mean proportions of each selenium species were 82 percent dissolved selenate, 9 percent dissolved selenite, 8 percent dissolved organic selenium, and 1 percent particulate selenium (Saiki et al. 2010).

Selenium enters the Salton Sea as highly soluble salt (primarily selenate and selenite) and accumulates in the anoxic sediments on the Sea floor (DWR and DFG 2007). Waterborne concentrations are rapidly reduced to less than 2 µg/L as selenium assimilates into biota and settles into organically rich sediments. The anoxic nature of the Sea's sediments is important in trapping selenium in insoluble, nonbioavailable forms of selenite, elemental selenium, and selenide.

Table I-1 Selenium Concentrations in Water

Location	Selenium Concentration (µg/L)		Year(s)	Notes and Source
	Mean	Range		
Salton Sea	1.16	0.98 – 2.94	2004–2009	Three surface samples near middle of the Salton Sea. Mean calculated from annual means for 6 years (2004–2009) Reclamation (unpublished data, C. Holdren)
	2.46	1.9 – 3.2	2006–2008	Near southern shore Miles et al. 2009
Whitewater River	2.23	1.27 – 2.86	2004–2009	Mean calculated from annual means for 6 years (2004–2009) Reclamation (unpublished data, C. Holdren)
Alamo River	5.09	4.22 – 6.78	2004–2009	Mean calculated from annual means for 6 years (2004–2009) Reclamation (unpublished data, C. Holdren)
	5.88	5.2 – 7.0	2006–2008	Miles et al. 2009
	4.1		2010	Amrhein and Smith 2011
New River	3.18	2.88 – 4.21	2004–2009	Mean calculated from annual means for 6 years (2004–2009) Reclamation (unpublished data, C. Holdren)
	1.8		2010	Amrhein and Smith 2011
New River (upstream) Imperial Wetlands Brawley Wetlands		2.7-5.4 2.2 – 3.9	2006–2007	River inflow to treatment wetlands Johnson et al. 2009
Agricultural drains into southern Salton Sea	4.18	0.79 – 79.1	2005–2009	29 drains and ponds Saiki et al. 2010

In 2006, Reclamation constructed a 50-hectare experimental SHP complex of four interconnected shallow saline ponds on the Sea's southern end. The USGS monitored water quality and biota at this site during 2006–2008 (Miles et al. 2009). The ponds were filled in 2006 with waters blended from the Alamo River (5.2 – to 7.0 µg/L selenium) and the Salton Sea (1.9 to 3.2 µg/L selenium). The blended waters had a selenium concentration of less than 5 µg/L flowing into the ponds. The water from the final pond (Pond 4) was sometimes recirculated to the first pond.

Salinity and selenium concentrations varied among these ponds and over time (Table I-2). The highest concentration measured was in Pond 4 (5.7 µg/L, Spring 2008). The effect of time was not consistent across all ponds. Sediment selenium concentrations increased over time in Ponds 1 and 2, relative to a slight decrease at Pond 4 (Miles et al. 2009). Selenium concentrations were typically below the Basin

Plan water standard (5 µg/L), but often exceeded Lemly's (2002) more conservative toxicity threshold (2.0 µg/L).

Table I-2 Salinity and Selenium Concentrations at Reclamation/USGS Saline Habitat Ponds

Constituent	Pond	Fall 2006	Spring 2007	Fall 2007	Spring 2008	Fall 2008
Salinity (parts per thousand [ppt])	1	6.5	24.1	4.2	13.0	21.2
	2	16.8	29.8	9.1	29.0	24.9
	3	30.9	58.9	29.9	70.7	47.6
	4	>70 *	174.0	153.3	335.0	398.0
Total Selenium in Water (µg/L)	1	3.9	1.9	2.0	3.0	2.6
	2	2.4	1.9	0.9	1.9	1.5
	3	2.7	2.7	1.2	1.6	1.7
	4	3.8	3.0	3.4	5.7	3.2
Total Selenium in Sediments (µg/g dw)	1	1.03	1.38	2.15	2.32	2.22
	2	0.94	1.25	1.37	1.31	1.61
	3	1.83	2.99	3.00	2.06	2.12
	4	1.67	2.44	2.35	1.97	1.92

Source: Miles et al. 2009

* Value exceeded measuring device capacity

I.2.3 Selenium in Sediment

The SCH ponds would be constructed on recently exposed or soon-to-be exposed playa. Selenium concentrations in sediment were measured in 2010 at proposed Project sites adjacent to the mouths of the Alamo and New rivers. Mean sediment selenium concentrations were 1.1 mg/kg (range 0.54 to 2.3 mg/kg). The majority of sediment samples (63 percent) were less than 1 mg/kg of selenium and would be considered "low risk." The remaining 37 percent of the samples were between 1 and 4 mg/kg (only two samples exceeded 2.5 mg/kg) and were considered in the "level-of-concern" category. No sample exceeded the "toxicity threshold" value of 4 mg/kg (Amrhein and Smith 2011).

Selenium could accumulate and concentrate in the SCH pond sediments over time. USGS monitored the experimental SHPs that were flooded in 2006 with water from the Alamo River and Salton Sea (Miles et al. 2009). Mean selenium concentrations in sediment were 1.03 to 2.32 mg/kg in Pond 1, 0.94 to 1.61 mg/kg in Pond 2, 1.73 to 3.00 mg/kg in Pond 3, and 1.67 to 2.35 mg/kg in Pond 4. Sediment selenium concentrations increased in Ponds 1 and 2 and decreased in Pond 4. Sediment concentrations did not exceed the 4.0 mg/kg toxicity threshold after nearly 3 years of operation. It was uncertain, however, whether the system had reached equilibrium (personal communication, R. Gersberg 2010).

Rewetting of the dried sediments when filling the newly constructed SCH ponds has the potential to solubilize and release selenium into the water (Byron and Ohlendorf 2007). Oxidized selenium is present in the exposed playa sediments that would be inundated. Experiments have measured selenium release from newly wetted sediment samples from the mouths of the New and Alamo rivers (Byron and Ohlendorf 2007, Amrhein et al 2011). Byron and Ohlendorf (2007) conducted a laboratory experiment using intact cores of Sea sediment with overlying Sea water and documented the effects of dissolved oxygen level (oxic, anoxic) and salinity (2, 20, or 35 parts per thousand [ppt]) on selenium flux. Higher positive flux from sediments into water was observed under oxic conditions and at the lowest salinity values. Selenium flux from the water to the sediment dominated at salinities of 20 and 35 ppt. Dissolved selenite (Se IV) and organic selenium compounds predominated in the overlying water. Results imply that selenium in overlying water is likely to be sequestered to the sediment under future highly saline conditions, as it is today, but may be released into the overlying water if water salinity is very low or if oxygenation is enhanced over current conditions.

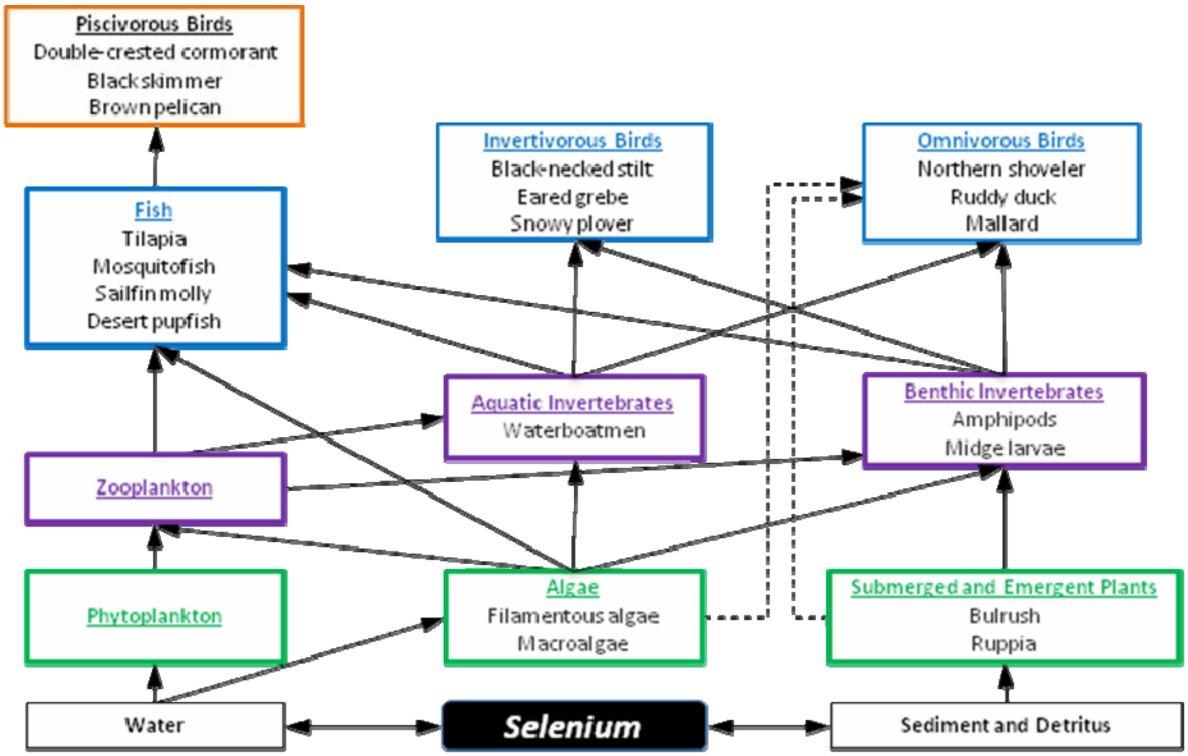
Amrhein and others (2011) incubated sediment taken near the mouth of Alamo River for up to 235 days with well-aerated water at salinities approximating 2.1 and 13.7 ppt. This experiment was designed to maximize sediment oxidation (well-mixed, well-aerated, high solution/sediment ratio). The amount of selenium in sediments was positively related to organic carbon, suggesting the primary pathway for selenium accumulation in the Salton Sea is algal uptake of soluble selenium from the water and deposition of algal detritus in sediments, as previously described in the PEIR (DWR and DFG 2007). Cumulative release of selenium from playa sediments over 194 and 235 days ranged widely (6 to 50 micrograms per kilogram, 1 to 21 percent of total sediment selenium). However, oxidation rates and amount solubilized did not appear affected by carbon content, salinity, location, or depth of sample core. Rather, the release of selenium appeared controlled by the amount of oxidizable iron present in sediments. If iron was present, the oxidized selenium adsorbed onto the iron and remained in the sediment, and less selenium would dissolve into pondwater. Therefore, water-soluble selenium (selenate) concentrations over high-iron sediments would be lower compared to low-iron sediments, and less selenium would be available for uptake into the food web via the algal pathway. This particulate-bound selenium (selenite) could still get into the food web through ingestion by benthic organisms and, subsequently, by fish and birds. Nevertheless, the volume of dissolved selenium from inflow water would likely pose a greater relative risk to wildlife bioaccumulation than selenium from sediment (Amrhein et al. 2011).

To compare selenium release from flooded and exposed sediments, Amrhein and others (2011) also measured selenium concentrations after 1 hour of wetting 3 different sediment samples (currently flooded, drained for about 1 month and 2 months due to the receding Salton Sea). Water-soluble selenium concentrations were twice as high from sites drained for 1 month (about 4 µg/L) and 3-4 times higher from sediments drained for 2 months (about 6 to 8 µg/L), compared to flooded sites (about 2 µg/L). This result is consistent with the concept of an initial "flush" following inundation. Because this experiment was well mixed and well aerated, undisturbed sediments should release selenium more slowly. SCH managers could decrease residence times (i.e., more flow-through) to flush soluble selenium out of the ponds. Selenium solubilization from sediments likely declines over time, as suggested by findings from the SHP complex, where the frequency of elevated egg selenium concentrations declined after the 1st year (Miles et al. 2009). The volume of dissolved selenium from inflow water would likely pose a greater relative risk to wildlife bioaccumulation than selenium from sediment (Amrhein et al. 2011).

I.3 ECOLOGICAL RISK ASSESSMENT

I.3.1 Ecological Receptors and Exposure Pathways

Selenium can adsorb onto organic particulate matter such as detritus, be ingested by invertebrates or fish, and bioaccumulate within aquatic food webs (Figure I-1). Selenium in the water or sediment may be transferred up the food web through attached or free-floating microorganisms or rooted submerged and emergent plants (primary producers or consumers). As selenium is transferred into the benthic or water-column invertebrates, fish or birds (secondary or tertiary consumers) may then consume it. Alternatively, the selenium pathway to higher-order aquatic and benthic invertebrates, fish, and birds may also occur directly through contact with or ingestion of water and sediment (DWR and DFG 2007).



Not all possible pathways depicted, such as detritus to invertebrates and some fish.

Figure I-1 Selenium Cycling and Transport Pathways

Selenium concentrations have been measured in various biota at the Salton Sea area, including algae, vegetation, invertebrates, fish, and bird eggs (Table I-3) (DWR and DFG 2007; Johnson et al. 2009; Miles et al. 2009; Saiki et al. 2010).

Invertebrates

Aquatic (water-column) and benthic invertebrates (including zooplankton) are found in marine, estuarine, and freshwater habitats. Aquatic and benthic invertebrates can include primary consumers that ingest sediment and surface water during feeding or burrowing. Aquatic and benthic invertebrates are a major route of food-chain transfer in the Salton Sea food chain (DWR and DFG 2007). The suggested toxicity threshold for invertebrates as prey (to avoid bioaccumulation in birds) is 3 to 4 µg/g dw (Hamilton 2004). However, selenium concentrations observed at the Salton Sea vary widely among locations and taxa (Table I-3) and frequently exceed this threshold. At the SHP complex, mean concentrations exceeded 4.0 µg/g dw in 67 to 80 percent of corixid samples and 0 to 30 percent of chironomid samples (Miles et al. 2009). In the IID agricultural drains, selenium concentrations in chironomids were an order of magnitude higher (Saiki et al. 2010).

Table I-3 Mean Selenium Concentrations in Water, Sediment and Biota

Location	Water (µg/L)	Sediment (µg/g dw)	Aquatic Plant µg/g dw	Invertebrate (µg/g dw)	Fish (µg/g dw)	Bird Eggs (µg/g dw)
Salton Sea - Open Water [1] (mean and range)	-	-	0.83 (0.2-1.1)	-	10.4 (4.37 - 25.7)	
Salton Sea - Shoreline and Shallow Water[1] (mean and range)	-	-	0.72 (0.4-1.3)	6.64 (0.82-12.1)	-	5.98 (0.54-14.2)
Salton Sea[2] (range of means)	1.9-3.2	1.42-2.42	-	2.37 - 3.64	-	5.41 (Morton Bay)
Alamo River Estuary[1] (mean and range)	-	-	-	4.25 (0.7-5.7)	11.5 (4.3 - 27.9)	
New River Estuary[1] (mean and range)	-	-	-	2.7 (2.5-2.9)	9.67 (3.5-17.0)	2.81 (1.9- 3.7)
Saline Habitat Ponds[2] (range of means)	1.2-3.9	0.94-2.44	-	2.16 - 8.50	-	4.52 - 9.09
Sonny Bono National Wildlife Refuge[2] (range of means)	0.7-1.1	0.38-0.61	-	0.92 - 2.31	-	2.18 - 4.42
Freshwater Marsh[2] (range of means)	2.0-4.2	1.73-2.67	-	2.05 - 2.83	-	5.6 - 7.05
Agricultural Drains[3] (mean and range)	5.62 (0.70-32.8)	1.43 (0.33-10.0)	2.22 (0.75-8.26)	Chironomid 6.50 (1.39-50.6)	Mosquitofish 6.81 (3.66-20.2) Salfin molly 6.89 (3.09-30.4)	-
New River Imperial Wetlands[4] (median and range)	(2.7-5.4)	0.3 (0.2-0.8)	-	Corixid, glass shrimp, Odonate, 4.1 (2.8-5.2)	Carp 4.4 Shad 4.7 (3.3-20.0)	-
New River Brawley Wetlands[4] (median and range)	(2.2-3.9)	0.4 (0.4-0.5)	-	Corixid, Odonate, glass shrimp, crayfish 2.6-3.8 (1.5-8.2)	Carp 4.0 Shad 2.8 Tilapia 4.5 (1.9-7.3)	-

1. DWR and DFG 2007, Appendix F
2. Miles et al. 2009. Saline Habitat Ponds supplied with Salton Sea and Alamo River waters, Sonny Bono National Wildlife Refuge supplied by Colorado River water, Freshwater Marsh supplied with agricultural drainwater.
3. Saiki et al. 2010. Seven IID agricultural drains in southern Salton Sea.
4. Johnson et al. 2009.

Fish

Fish may be exposed to selenium in sediment or surface water through ingestion, dermal contact, uptake through gills, and by feeding on contaminated plants, aquatic invertebrates or smaller fish. Likely fish species at the SCH ponds include tilapia, sailfin molly, western mosquitofish, and desert pupfish. Fish can be primary, secondary or tertiary consumers. Tilapia are omnivorous and forage on detritus, algae, phytoplankton and invertebrates. The food-chain pathway is the most important route of exposure for fish, which also are a major route of food-chain transfer to higher trophic levels such as birds.

Mean whole-body fish selenium concentrations were 10.4 µg/g dw in the open Salton Sea, 9.67 µg/g dw in the New River Estuary, 11.5 µg/g dw in the Alamo River Estuary (DWR and DFG 2007, Appendix F), 6.81 to 6.89 µg/g dw in IID agricultural drains (Saiki et al. 2010), and 2.8 to 4.7 µg/g dw in New River wetlands upstream (Johnson et al. 2009). Sailfin mollies and moquitofish did not appear to be adversely affected at concentrations of 3.1 to 30.4 µg/g dw, and pupfish in laboratory experiments did not exhibit negative health effects from such levels of selenium exposure (Saiki et al. 2010).

Birds

Selenium's most substantial effects occur in bird embryos, such as reduced hatching success and teratogenesis. While many bird species use the Salton Sea ecosystem for a part or all of their lives (summer breeding, wintering, or migratory stopover), the target bird species for this ecological risk analysis are those species that both breed at the Salton Sea and feed on aquatic invertebrates and fish expected to occur in the SCH ponds. The effects of selenium exposure from the SCH Project on species breeding elsewhere would be temporary and likely to be negligible, based on laboratory feeding studies that showed that selenium is depurated (lost) from the birds within about 2 weeks once selenium-treated food is removed (Ohlendorf and Heinz 2011). Breeding species that could be exposed at the SCH ponds include California brown pelican, double-crested cormorant, Caspian tern, black skimmer, gull-billed tern, black-necked stilt, and western snowy plover.

Mean egg selenium concentrations were 4.52 to 9.09 µg/g dw at the SHP complex (black-necked stilt, Miles et al. 2009), 5.98 µg/g dw at Salton Sea shoreline (DWR and DFG 2007), and 2.81 µg/g dw at New River estuary (DWR and DFG 2007).

California Brown Pelican

The California brown pelican occurs at the Salton Sea as newly fledged young and post-breeding adults as they disperse from nesting areas in Baja California. During summer, brown pelicans forage around the Sea's margin. In recent years, brown pelicans have nested in small numbers, especially at the Sea's southern end at the mouth of the Alamo River (Molina and Sturm 2004). In 2009, California brown pelicans were most abundant in August with almost 3,000 individuals recorded near and within the Project area; numbers declined in the fall but the species remained a consistent visitor throughout the year (USFWS 2010). This species was observed during Summer 2010 surveys foraging within the Sea at the mouths of the New and Alamo rivers and along the shoreline (Dudek 2010); suitable roosting and loafing habitat includes sandbars, islands, and rocky areas within the Project area.

Brown pelicans are expected to forage often at the SCH ponds for fish, as well as at the mouths of nearby rivers where fish may persist in the deltas.

Double-Crested Cormorant

The double-crested cormorant is a California Species of Special Concern. Cormorants are yearlong residents along the California coast and the Salton Sea. They feed primarily on fish, but also crustaceans and aquatic insects. Nesting habitat requirements include undisturbed areas near water and may consist of rock ledges on cliffs, rugged slopes, and live or dead trees. Breeding at the Salton Sea begins with nest building in late January (Patten et al. 2003) and may extend to July or August, though only one brood is produced (Zeiner et al. 1990, as cited in DWR and DFG 2007). Double-crested cormorants nest in colonies and usually lay three or four eggs (Udvardy 1993, as cited in DWR and DFG 2007).

Double-crested cormorants are expected to forage often at the SCH ponds, as well as at the mouths of nearby rivers where fish may persist in the deltas.

Black Skimmer

The black skimmer is a California Species of Special Concern. It is a fairly common summer resident and breeder at the Salton Sea, arriving by late April and departing by October. Nesting at the Sea's southern end begins in May and continues into the early fall, depending on the Sea's water levels (Patten et al. 2003). They typically breed on sandy islands or sandy areas in salt marshes and they can breed on isolated sections of eroded impoundment levees. They nest in colonies and produce one clutch per year with one to five eggs (four or five are most common) (Zeiner et al. 1990, as cited in DWR and DFG 2007). Black skimmers forage on small fish and crustaceans and prefer areas near river mouths and other water channels at the Salton Sea.

Black skimmers are expected to forage often at the SCH ponds for fish, as well as at the mouths of nearby rivers where fish may persist in the deltas.

Caspian Tern

The Caspian tern is a common breeding bird that occurs within the Salton Sea region from mid-April through October. It is most abundant at the Sea from late summer through fall. Most Caspian terns depart from the region by the end of October, but some remain through the winter (Patten et al. 2003). Caspian terns forage primarily or exclusively for fish but may occasionally take crayfish and insects (Cuthbert and Wires 1999). Approximately 25 percent of the North American population of the Caspian tern breeds at the Salton Sea (Cuthbert and Wires 1999; personal communication, K. Molina 2010). In 2009, the population size within the Project area was in the hundreds for the winter months and in the thousands for the breeding season (USFWS 2010). In 2010, nesting numbers of Caspian terns were up to several thousand breeding pairs, predominantly on Mullet Island and the D pond islands but also along Morton Bay's shore (personal communication, K. Molina 2010).

Caspian terns are expected to forage often at the SCH ponds for fish, as well as at the mouths of nearby rivers where fish may persist in the deltas.

Gull-Billed Tern

The gull-billed tern is a California Species of Special Concern. They arrive at the Salton Sea in mid-March and remain until October. Gull-billed terns nest on protected spits, berms, and islands composed of sand or barnacle shells; at the Salton Sea, they also nest on earthen levees and on constructed islands in shallow brackish impoundments. For Salton Sea colonies, available nesting substrates include fine, poorly drained, clay soils devoid of all vegetation with cobbles and boulders located sparsely. Nests are often located adjacent to cobbles, boulders, or other debris. Gull-billed terns forage primarily in freshwater ponds and flooded agricultural fields. Foraging habitat within the Project area would likely include agricultural fields, marshes, mudflats, drainage ditches, and fresh or saline open water. At the Salton Sea, the species forages for small fish, crayfish, lizards, butterflies, beetles, crickets, weevils, and occasionally, the young chicks of other shorebirds (DWR and DFG 2007).

Gull-billed terns are expected to forage occasionally at the SCH ponds, but their diet will be predominantly from other sources in the surrounding landscape.

Black-Necked Stilt

The black-necked stilt is a yearlong, fairly common resident at the Salton Sea (Patten et al. 2003). This shorebird prefers lakeshores, flooded alkali flats, saltponds, coastal estuaries, and flooded fields. Nesting habitat includes friable soil, mudflats, levees, or dry lakeshores near water. Nesting mainly occurs April through June (Patten et al. 2003). The clutch size averages four, with a range of three to five (Zeiner et al. 1990, as cited in DWR and DFG 2007). Black-necked stilt forages in shallow water for insects, crustaceans, mollusks, and other aquatic organisms, including some small fish.

Recent studies at the experimental SHP complex measured selenium in black-necked stilt eggs (2006, 2007, 2008) (Miles et al. 2009). Black-necked stilt are considered moderately sensitive to selenium (Skorupa 1998). Selenium concentrations in black-necked stilt eggs (2-8 µg/g dw, mean 5 µg/g dw) at the SHP complex were significantly higher than eggs from reference sites for 2 out of the 3 years, and 47 percent of the eggs exceeded the selenium toxicity threshold of 6.0 µg/g dw (Miles et al. 2009). Anderson (2008) reported that selenium concentrations in stilt eggs in SHP ponds were elevated, but concentrations were similar to those found in other stilt nesting habitats in the Salton Sea. Stilts were tracked feeding in both ponds and the Salton Sea, however, and therefore the egg selenium concentrations reflect a composite of prey from multiple sources and potentially different selenium levels. Miles and others (2009) "did not detect any relationship between selenium and embryonic malpositioning or post-hatch survival of stilt chicks, or a high frequency of embryonic deformities associated with selenium toxicity. Therefore, although a selenium risk was indicated at the SHP complex, it was not manifested by a reduction in the productivity parameters measured in [stilts]".

Black-necked stilts are expected to forage for invertebrates and some fish at the SCH ponds in the shallow margins, as well as at other shoreline habitats that persist nearby.

Western Snowy Plover

The snowy plover is a California Species of Special Concern. The western snowy plover regularly winters and breeds along the Salton Sea's shoreline. It nests during the spring and summer on open beaches with sand and barnacle substrates and in close proximity to standing water. Nesting occurs within about 1,000 feet of the Sea's edge (personal communication, K. Molina 2010). Breeding has been noted to be concentrated on the Sea's western side from Desert Shores to the mouth of San Felipe Creek and on the eastern side from Bombay Beach to Wister Unit (Patten et al. 2003). The western snowy plover also forages along the Sea's shoreline, mostly on the sand and barnacle beaches. It will also forage in shallow impoundments with exposed mud. Suitable habitat for foraging and breeding within the Project area includes the mudflats along the Sea's shoreline. Snowy plovers eat terrestrial and aquatic invertebrates, utilizing beaches, tideflats, saltflats, and salt ponds while foraging above and below the high water line (Page et al. 1995, as cited in DWR and DFG 2007).

Western snowy plovers are expected to forage for invertebrates at the SCH ponds in those areas shallow enough for this small shorebird.

I.3.2 Toxicity Reference Values

Designation of toxicity thresholds for selenium in biota has varied (Amrhein and Smith 2011; Ohlendorf and Heinz 2011). Lemly (2002) proposed no more than 3 µg/g dw in food-chain organisms, and 4 µg/g dw in whole-body fish. This fish threshold is a general standard protective of the most sensitive fish species; the fish species likely to colonize the SCH ponds are less sensitive to selenium (Saiki et al. 2010; personal communication, M. Saiki, 2011).

In bird eggs, 6 µg/g dw is a conservative and widely reported toxicity reference value (Ohlendorf and Heinz 2011). The responses to selenium vary among bird species, ranging from "sensitive" (mallard) to "average" (stilt) and "tolerant" (avocet) (Skorupa 1998, as cited in Ohlendorf and Heinz 2011). Risk of impaired reproduction can start to occur at egg concentrations of 6 to 12 µg/g dw (Table I-4). The risk of teratogenesis starts to occur above 12 µg/g dw for sensitive species and above 20 µg/g dw for moderately sensitive species (Ohlendorf and Heinz 2011). Cormorants and terns are likely to be fairly tolerant of selenium, in keeping with greater tolerance of other saltwater-adapted species such as avocets and snowy plover, compared to freshwater-adapted species such as mallards (personal communication, H. Ohlendorf, 2010).

Table I-4 Selenium Thresholds and Effects on Birds

Selenium Concentration (µg/g dw)	Probability of Effects on Birds	
	Reproductive Impairment (reduced hatching success)	Teratogenic Effects
<3.0 mean, <5.0 individual eggs	None - Background level	None - background level
<6	None	None
6 to <8	Low probability	None
8 to <12	Elevated probability for sensitive species (mallard)	None
12 to <20	Elevated for sensitive (mallard) and "average sensitivity" species (black-necked stilt)	Low probability
>20 to 35	Elevated probability	Elevated probability for sensitive species (mallard)
>35	Elevated probability	Elevated for "average sensitivity" species (black-necked stilt)

Source: Ohlendorf and Heinz 2011

I.3.3 Ecological Risk Modeling

Modeling of selenium bioaccumulation within food webs of the SCH ponds was used to predict the selenium levels in water and sediments of the SCH ponds and the range of concentrations of selenium in the tissues of fish and birds utilizing the SCH habitats. This section summarizes results of ecological risk modeling performed by UCR (Sickman et al. 2011).

Approach and Methodology

Sickman and others (2011) used the modeling approach of Presser and Luoma (2010) to simulate transformation of dissolved selenium into particulate organic matter and selenium bioaccumulation rates among trophic levels. The SCH selenium conceptual model simulates the mixing of river and Sea water to attain a specified salinity level and assumes that selenium mixing is conservative. Next, the model transforms dissolved selenium into particulate matter using a partitioning coefficient (K_d value [Presser and Luoma 2010]). Particulate selenium pools included sediments and organic detritus (including associated microbial biomass) and algae and phytoplankton. Once selenium becomes bound to organic particulate matter it is consumed by invertebrates and the bioaccumulation rate is estimated using a trophic transfer factor (TTF) derived from field measurements. Within the model, the particulate selenium pool was conceptualized to be the first level of the food web. Invertebrates (chironomids, corixids) represent the second level of the food web. Invertebrates are in turn preyed upon by fish (tilapia, mosquitofish and sailfin mollies) or invertebrate-consuming birds (black-necked stilts), which represent the third level of the food web. The fourth level of the food web represents predation of fish by piscivorous birds (terns, cormorants). Understanding of selenium transfer into particulate matter and bioaccumulation and effects in piscivorous birds are major knowledge gaps at the Salton Sea (Sickman et al. 2011).

The assessment endpoint for all birds was reproduction, since reproductive effects are the most sensitive indicator of selenium toxicosis (Ohlendorf and Heinz 2011). The metric used was the selenium concentration of bird eggs (Sickman et al. 2011). These models are progressive in structure since they simulate and track the movement of selenium as it progresses from dissolved forms into particulate matter through the food chain.

Parameters used in the General Models were computed from all available studies in and around the Salton Sea. Given significant differences in waterborne selenium concentrations, separate General Models were made for SCH ponds utilizing either Alamo River or New River water, blended with Salton Sea water to achieve operational salinity targets of 20 and 35 ppt. Separate General Models were constructed for food webs containing invertebrate-consuming birds and food webs containing fish-consuming birds (Sickman et al. 2011). Different questions were addressed with various simulations using different K_ds and TTFs, and the most applicable simulations are reported here:

Expected Water Quality. This simulation answers the question: "How much selenium would be in the biota from SCH ponds, given different sources and salinities of water supplying the ponds?" The model was run in a "forward" direction starting from initial selenium concentrations in water to produce estimates of selenium concentrations in whole-body fish and in bird eggs. This scenario utilized median values for K_d and TTFs and the median water quality parameters.

Future Scenario/River Only - 10 µg/L Rivers. This scenario simulates conditions in the future after the Salton Sea has reached excessively high salinity levels and is no longer used to supply SCH ponds with water.[3] In this hypothetical future worst case scenario, the ponds would instead be supplied only by river water, which has a total selenium concentration of up to 10 µg/L. Median K_d values were used in this future scenario.

Inverse Modeling. This simulation answers the question: "How much river water can be used in the SCH ponds before birds exhibit reduced egg viability?" Because the dissolved selenium concentrations in the Alamo and New rivers are substantially higher than in the Salton Sea, all things being equal, the selenium risk increases with decreasing SCH salinity because more river water is required to reach the target salinity. The model was run backwards to compute the maximum acceptable dissolved selenium concentration and ultimately the mixture of Sea and river water necessary to not exceed various selenium concentrations in bird eggs (6, 8, or 12 µg/g dw).

Results

Expected Water Quality Simulation

Overall, the models suggest that fish and bird eggs in SCH ponds utilizing Alamo River water will have about 50 percent higher selenium concentrations than with the same salinity in SCH ponds utilizing New River water (Table I-5). This result is due to higher dissolved selenium levels in the Alamo River water relative to the New River. Similarly, risk increases as salinity decreases, with about 25 to 30 percent higher selenium concentrations predicted at a salinity of 20 ppt relative to 35 ppt. Recall that higher risk at lower salinity is simply the outcome of greater water contributions of river water (higher total selenium concentrations) to reach lower salinity mixtures in the SCH ponds (Sickman et al. 2011).

[3] Salinity in the Salton Sea is projected to reach 250 ppt by the year 2068 (Appendix H-2, DWR and DFG 2007 If Sea and river water were then blended to achieve saline conditions, inflow for the SCH ponds would be 13 percent Sea water to achieve 35 ppt (selenium concentration 8.9 µg/L) or 7 percent Sea water to achieve 20 ppt (9.4 µg/L). Simulation 3 represents a worst-case scenario of all-river water (10 µg/L).

Table I-5 Modeled Selenium Concentrations in Biota

River Source	Salinity	Water (µg/L)	Macroinvertebrates	Fish (whole)	Bird Eggs (Invertebrate Eaters)	Bird Eggs (Fish Eaters)
New River	20 ppt	2.6	4.2	5.5	7.6	8.3
	35 ppt	2.0	3.3	4.3	6.0	6.5
Alamo River	20 ppt	4.0	6.6	8.5	11.6	12.7
	35 ppt	2.8	4.5	5.9	8.1	8.9

Selenium concentrations in biota = micrograms per gram dry weight (µg/g dw)
Source: Sickman et al. 2011 (General Model simulation)

Using expected water quality and median K_d values, the only modeling scenarios that produced egg selenium concentrations at or below the 6 µg/g effects level were SCH ponds supplied by the New River and operated at salinity of 35 ppt for those birds that eat primarily invertebrates (Table I-5). Less than 8 µg/g dw was predicted, under the expected water quality simulation, for invertebrate-consuming birds in New River SCH ponds at 20 ppt salinity, and in fish-consuming birds in New River SCH ponds at 35 ppt salinity. For Alamo River-supplied SCH ponds modeled under the expected water quality simulation, egg selenium concentrations of 8.1 to 12.7 µg/g dw were predicted depending on salinity (Sickman et al. 2011). Egg selenium concentrations would be greater in ponds operated at a lower salinity (20 ppt) than higher salinity (35 ppt) (Sickman et al. 2011). Therefore, it is anticipated that egg selenium concentrations of birds foraging at the SCH ponds would be greater than 6 µg/g dw but less than 12 µg/g dw, potentially resulting in reduced hatching success but not teratogenesis.

Future (River Water Only) Simulation

Under future, "worst-case" water quality conditions, using just river water if the Salton Sea becomes too salty to be mixed into the SCH ponds at any appreciable concentration, the models estimated egg selenium concentrations of 29.1 µg/g dw for invertebrate-eating birds and 31.8 µg/g dw for fish-eating birds. Selenium concentration estimates in the future scenario/river-only simulation suggest that serious reproductive effects would occur across a range of avian species and some species would experience teratogenic effects from selenium (comparing to effect levels in Table I-4) (Sickman et al. 2011).

Inverse Modeling Results

Results from the inverse modeling runs provide useful information for establishing salinity levels in the SCH ponds (Table I-6). Under expected water quality conditions, the Inverse Models predict that in order to keep egg selenium concentrations in invertebrate-consuming birds equal to or less than 6 µg/g dw, ponds supplied with New River water would have to be operated at salinities above 35 ppt and ponds supplied with Alamo River water would have to be operated above 44 ppt. To keep egg selenium concentrations of fish-eating birds equal to or less than 6 µg/g dw, ponds supplied with New River water would have to be operated above 39 ppt and ponds supplied with Alamo River water would have to be operated above 46 ppt (Sickman et al. 2011). A greater proportion of river water could be used if higher selenium concentrations would be tolerated in bird eggs, which would consequently result in lower salinity of water supplying the SCH ponds. For example, if egg selenium concentrations in both invertebrate-eating and fish-eating birds could be allowed reach up to 12 µg/g dw, then the SCH ponds using Alamo River water could be operated at 23 ppt, and SCH ponds using New River water could be operated with pure river water (Table I-6).

Table I-6 Predicted Salinity of SCH Ponds Necessary to Meet Target Selenium Concentrations in Bird Eggs

Target Selenium Concentration in Bird Eggs (dry weight)	Ponds Operated with New River Water				Ponds Operated with Alamo River Water			
	Invertebrate-Eating Birds		Fish-Eating Birds		Invertebrate-Eating Birds		Fish-Eating Birds	
	Selenium in Blended Water	Minimum Salinity of Blended Water	Selenium in Blended Water	Minimum Salinity of Blended Water	Selenium in Blended Water	Minimum Salinity of Blended Water	Selenium in Blended Water	Minimum Salinity of Blended Water
6 µg/g	2.06 µg/L	35 ppt	1.89 µg/L	39 ppt	2.06 µg/L	44 ppt	1.89 µg/L	46 ppt
8 µg/g	2.75 µg/L	17 ppt	2.52 µg/L	23 ppt	2.75 µg/L	36 ppt	2.52 µg/L	39 ppt
12 µg/g	4.12 µg/L	All-river source okay	3.78 µg/L	All-river source okay	4.12 µg/L	18 ppt	3.78 µg/L	23 ppt

Source: Sickman et al. 2011 (Inverse Model simulation, Appendix Tables 10a, 10b. 11a and 11b)

Reclamation/USGS SHP Pond Simulation

Data from the Reclamation/USGS SHP study (Miles et al. 2009) was also used to compute values for Kd and TTF to simulate selenium dynamics in experimental saline habitats, which are similar in design to the SCH ponds (Sickman et al. 2011). When the Reclamation/USGS SHP ponds model results are compared to the observed egg selenium concentrations of invertebrate-consuming birds in the Reclamation/USGS SHP complex (Table I-7), it can be seen that the modeled egg selenium concentrations are actually higher than those observed in the experimental ponds. Therefore, it is possible that the actual levels of selenium in the SCH ponds would be lower than those predicted by the model. Further, the observed levels of egg selenium concentrations of invertebrate-consuming birds from the reference sites were within the same range as those from the Reclamation/USGS SHP complex, suggesting that SCH ponds operated with comparable salinity levels would not significantly increase selenium ecological risk at the Salton Sea.

Table I-7 Observed and Modeled Selenium Concentrations in Invertebrate-Eating Birds at Reference Sites and SHP Complex

Site		Observed Selenium Concentrations						Modeled Selenium	
		Water (µg/L) Range			Black-Necked Stilt Eggs			Water[2] (µg/L)	Invert-Eating bird eggs
		2006	2007	2008	2006	2007	2008		
Reference Sites[1]	Freshwater Marsh	2.5	2.0-4.1	2.6-4.2	7.05	6.11	5.26	n/a	n/a
	D-Pond	0.9	0.7-0.8	0.9-1.1	3.62	2.18	4.42	n/a	n/a
SHP Ponds	Pond 1	3.9	1.9-2.0	2.6-3.0	7.85	6.18	5.45	2.7	13.1
	Pond 2	2.4	0.9-1.9	1.5-1.9	9.09	5.45	5.73	1.7	12.5
	Pond 3	2.7	1.2-2.7	1.7	--	6.06	6.99	2.0	6.2

1. Reference sites at Sonny Bono Salton Sea National Wildlife Refuge.
2. Model used mean values for selenium concentrations in water from each pond 2006–2008 (Miles et al. 2009).

Sources: Miles et al. 2009; Sickman et al. 2011

I.3.4 Conclusions

The modeling results yield several findings with relevance to SCH design and operation. First, the selenium risk in SCH ponds supplied with Alamo River water would likely be substantially higher than in ponds utilizing New River water. Risk characterization indices suggest moderate to high risk for reduced egg viability in black-necked stilts would occur in Alamo River-supplied SCH ponds and that the risks would be elevated above current risk levels (Sickman et al. 2011). Second, inverse modeling supports the premise that higher salinity levels would result in lower risk from selenium. Salinity of 35 ppt is recommended to reduce risk of reproductive effects (<6 µg/g dw). If low to moderate levels of reduced hatching success are deemed acceptable, then salinity levels closer to 20 ppt would be adequate for New River-supplied SCH ponds.

The magnitude of selenium impacts for the implemented Project could be lower than predicted by modeling. First, the ecological risk model assumed all diet comes from the SCH ponds, which could be true for species such as black-necked stilts and snowy plovers. The foraging range for many other birds (especially piscivores) would likely include other habitats beyond the SCH ponds, and those habitats (such as the freshwater ponds at the Sonny Bono Salton Sea National Wildlife Refuge, which receives Colorado River water) may have lower selenium levels. Thus, the true dietary exposure concentrations could be lower because the birds' foraging range would likely include other habitats beyond the SCH ponds. Second, when the model was run using parameters estimated from the SHP complex, the modeled egg selenium concentrations were greater than the actual measured egg concentrations (Miles et al. 2009), indicating that this model is a very conservative estimator of risk.

The model assumed that water residence time in the SCH ponds would be less than 32 weeks and that target salinity levels (20 and 35 ppt) would be reached primarily by mixing Salton Sea water with river water. Selenium concentrations in the Sea are lower than in the rivers and SCH salinity levels near the current condition in the Sea would produce the lowest dissolved selenium concentrations in the SCH ponds. Some evapoconcentration of constituents in water would occur with residence times near 32 weeks, although this is not expected to be true of selenium (personal communication, H. Ohlendorf, 2011). The data from Miles and others (2009) and the models suggest that residence times on the order of months would not appreciably increase selenium risk in the SCH ponds. While longer residence time could favor the conversion of selenate into more bioavailable forms of selenium, selenium concentrations decreased over time at other constructed habitats in the region, both in sediment of freshwater treatment wetlands (Johnson et al. 2009) and eggs from saline ponds (Miles et al. 2009), which suggests that selenium removal pathways could develop within the first 1 to 2 years after construction (Sickman et al. 2011).

I.4 MANAGEMENT STRATEGIES

The SCH ponds would be managed through a combination of source control and pond management to reduce selenium exposure and risk to biota, depending on the alternative chosen and Project operations. The levels of selenium at the SCH ponds would be monitored, at a minimum in the water, sediment, fish and bird eggs; and when feasible also particulate matter and invertebrates. If these measures do not reduce or mitigate risk to acceptable levels, then other measures including water treatment techniques would be considered; such potential actions, however, would not be part of this SCH Project.

I.4.1 Source Control and Minimization

Blend Waters to Reduce Selenium in Water Supply

Current selenium concentrations are greater in the Alamo River (5.1 to 5.8 µg/L) than the New River (3.2 to 3.5 µg/L). The modeling results suggest that selenium risk in SCH ponds would be reduced if New

River water were used instead of Alamo River water (Sickman et al. 2011). Another approach would be to "dilute" the river water with Salton Sea water (1 to 2 µg/L selenium). Therefore, the water supplied to the SCH ponds would be a blend of Salton Sea water and river water, which would be managed typically between 20 and 40 ppt and occasionally allowed up to 50 ppt with evaporation. The upper limit was selected based on expected tolerances of fish such as tilapia. Salinity of Salton Sea water is currently 53 ppt. However, low winter water temperatures can decrease the salinity tolerance of tilapia (Appendix J), so operational scenarios would likely have to balance these habitat requirements (Appendix D).

Control Vegetation to Reduce Bioaccumulation

Emergent and submerged vegetation can exacerbate selenium bioaccumulation because bioavailable forms of selenium can bioaccumulate in algae and phytoplankton or adsorb onto organic and/or particulate matter, where it is incorporated into the food web through uptake by benthic invertebrates and other detritivores. Plants such as pondweeds (e.g. *Ruppia*), cattail and bulrush can contribute appreciable amounts of organic matter that becomes detritus (Lemly 1998).

Higher salinity levels could be used in the SCH ponds to reduce or prevent the growth of emergent vegetation. For example, broad leaf cattail (*Typha latifolia*) has a typical salinity preference of 0 to 0.5 ppt, but has been found in intermediate marshes where salinities range up to 3.5 ppt (Stutzenbaker 1999). If salinity levels in the ponds were kept above 10 ppt, then many emergent vegetation species would be excluded from the ponds, reducing the risk of increased selenium bioaccumulation. Table I-8 presents salinity tolerances of several emergent plant species that could be present in the Project area.

The sedimentation basins would have very low-salinity water, which could support emergent vegetation as well as algae, phytoplankton and submerged vegetation. To discourage establishment of extensive emergent vegetation, they would be designed with steep sides and greater depths. Periodic maintenance of the sedimentation basins would include removal of accumulated sediment and organic matter that settled out from the river water and removal of any vegetation.

Flush the Ponds Following Initial Filling

It may be possible to flush some soluble selenium out of the ponds following initial filling of the ponds by decreasing the residence time (i.e., increasing flow-through rate) (Amrhein et al. 2011). Some evidence exists of selenium mobilization upon initial wetting of playa sediment (Amrhein et al. 2011). Sickman and others (2011) suggested that constructed freshwater and saline wetlands at the Salton Sea appear to develop selenium removal pathways within the first 1 to 2 years after construction. For example, at the Brawley and Imperial wetlands, appreciable amounts of selenium were sequestered or volatilized from the wetlands (Johnson et al. 2009). At the SHP complex, the percentage of stilt eggs that exceeded 6 µg/g dw declined from 77 percent during the 1st year of operation to an average of 44 percent in the 2nd and 3rd years (Miles et al. 2009).

Prevent Wildlife Access to Sedimentation Basins

The first pond where sediment would settle out is likely to have the highest concentrations of selenium (Miles et al. 2009). For the SCH Project, this location would be the sedimentation basin where river water is first diverted. Therefore, the sedimentation basin would be constructed and maintained to be deep with steep sides to discourage foraging and nesting by birds such as black-necked stilts. If necessary, other bird deterrent methods (e.g., Gorenzel and Salmon 2008) would be considered if selenium concentrations in the basins are at levels of concern and bird use is high.

Table I-8 Salinity Tolerances of Local Plant Species

Species	Habitat	Typical Salinity Preference	Widest Salinity Tolerated	Comments
American Bulrush (*Scirpus americanus*) Olney's Three-Square Bulrush *Schoenoplectus americanus*)	Fresh to intermediate marshes	0-3.5 ppt	50% reduction at 4 ppt and no germination above 13 ppt.	Stutzenbaker 1999; Uchytil 1992 Management and maintenance depends primarily on maintenance of water levels and secondarily on salinity levels (Uchytil 1992).
California Bulrush (*Schoenoplectus californicus*)	Widespread in fresh and intermediate marsh zone	0-3.5 ppt	Approximately 10 ppt or greater will control populations.	Stutzenbaker 1999 Prolonged exposure to extreme conditions (15 to 20 ppt) exceeds the typical salinity tolerance and populations decline (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2002).
Saltmarsh Bulrush (*Scirpus maritimus* or *Scirpus robustus*)	Intermediate to brackish marshes, often on soils subject to tidal influence	3.5-10 ppt	Has been found in hypersaline lakes (~60 ppt). Germination reduced 50% at salinity = 9 ppt. No germination at salinity = 21 ppt.	Stutzenbaker 1999; International Lake Environment Committee 1998; Snyder 1991
Broad Leaf Cattail (*Typha latifolia*)	Freshwater aquatic normally, but also found in intermediate marshes	0-0.5 ppt	Found in intermediate marshes with salinity up to 3.5 ppt . In marshes of southeastern Louisiana, occurred at salt levels up to 1.13%.	Stutzenbaker 1999
Narrow Leaf Cattail (*Typha angustifolia*)	Freshwater aquatic normally, but also found in intermediate marshes; coastal	0-0.5 ppt	15-30 ppt.	Stutzenbaker 1999; Reed et al. 1995
Southern Cattail (*Typha domingensis*)	Wetlands ranging from fresh to brackish	0-10 ppt	75% mortality occurred at 15 ppt.	Stutzenbaker 1999; Glenn et al. 1995

I.4.2 Water Treatment

If the various source control and mitigation measures outlined above do not sufficiently reduce ecological risk from selenium, it may be necessary to consider water treatment techniques as part of adaptive management. However, water treatment would not be implemented as part of the SCH Project.

Further evaluation would be required for any consideration of water treatment. Any process used would have to be capable of treating large water volumes with low concentrations of selenium (less than 10 μg/L) to achieve selenium concentrations less than 5 μg/L in inflow water, based on the Colorado River Basin Regional Water Quality Control Board (2006) standard, and possibly less than 2 μg/L. The amount of river water that would require treatment would depend on the Project alternative chosen, the number and size (volume) of ponds constructed, and the salinity of pond operations (typically 20 - 40 ppt). An average diversion rate of 50 cubic feet per second (approximately 32.3 million gallons per day or 22,500 gallons per minute) would accommodate some flow-through (outflow) as well as evaporation. Only river water would need to be treated, since Salton Sea water has selenium concentrations less than 2 μg/L.

The effectiveness and costs of a variety of physical, chemical, and biological technologies were evaluated in the *Selenium Treatment Technologies Report* (Cardno ENTRIX 2010). Although several treatment technologies have the potential to remove selenium, few have reliably reduced selenium concentrations to less than 5 μg/L at any scale, and still fewer have been successfully implemented at full-scale for sufficient time to demonstrate the long-term feasibility of selenium removal technology (CH2M Hill 2010). Physical treatments (reverse osmosis, nanofiltration) can be very effective, but are cost prohibitive for the SCH Project. Biological treatment (e.g., constructed treatment wetlands, controlled eutrophication using algae) appears to have the most applicability, although consensus is lacking among experts and in the literature (Cardno ENTRIX 2010).

Many questions would need to be resolved if constructed treatment wetlands were considered as a future management strategy. A primary issue is whether treatment wetlands at this scale could reliably reduce water selenium concentrations to less than 5 μg/L or even 2 μg/L. The removal of selenium by biological volatilization to the atmosphere is highly desirable because it leads to a net loss from the aquatic system, thereby preventing its entry into the food chain. One approach is to investigate ways to enhance volatilization (Lin and Terry 2003) either by selecting wetland plant species that are more effective at volatilization or by adding a carbon source (e.g., molasses) to the treatment wetland to stimulate bacterial processes and, thus, enhance volatilization. A study currently underway by UCB is evaluating the effectiveness of using a water treatment system that incorporates constructed wetlands to manage selenium (personal communication, N. Terry 2011). Preliminary laboratory mesocosm experiments suggest that different wetland designs and management techniques have the potential to reduce selenium concentrations to levels substantially lower than 5 μg/L. The next phase of the work will include a pilot wetland study to see if laboratory results could be transferred into the field. The Brawley and Imperial constructed wetlands provide another opportunity to test enhancement methodologies that could be scaled up to treat river flows before discharge to the SCH ponds (e.g., Johnson et al. 2009). Other biological treatment technologies such as algal treatment (e.g., Controlled Eutrophication Process) may further remove selenium and could be combined with constructed wetlands as a polishing step.

Another issue would be the potential ecological risk to wildlife from exposure at the treatment wetland itself, which would sequester and likely accumulate selenium within its sediments, detritus, and biota. Dense vegetation would increase the amount of particulate detritus in the system that could adsorb selenium. Design features and strategies to reduce wildlife exposure would need to be included. For example, wetlands could be designed with dense plantings to reduce the amount of open water habitat. This may deter open water species such as waterfowl and terns, but is likely to be less effective for other marsh species such as rails. Other bird deterrent methods (e.g., Gorenzel and Salmon 2008) may be necessary to dissuade birds from utilizing the treatment wetlands.

I.5 MONITORING AND STUDY

The SCH Project includes a monitoring and adaptive management framework (Appendix E) to guide evaluation and improved management of the newly created habitat, as well as to inform future restoration. Monitoring is a necessary component to obtain information on progress in meeting Project objectives, such as minimizing ecological risk from selenium. This section briefly outlines monitoring specifically for selenium, and identifies remaining uncertainties that are priorities for future study. Although monitoring is a part of the SCH Project, these potential studies, are not currently included.

I.5.1 Monitoring

Selenium in Water and Sediments

Selenium concentrations in water would be measured at various representative locations including the source waters for the ponds (both Salton Sea and river), in the sedimentation basin, blended influent water to the ponds after the sedimentation basin, habitat ponds, and outfalls. Surficial sediment samples (top 5 cm) and particulate matter from the sedimentation basin and habitat ponds would be tested for selenium. Sampling would be conducted quarterly for water and once or twice a year for sediment, and/or when water operations change, such as seasonal adjustments in salinity of inflow water. Speciation of selenium would be conducted for selected subsamples. Monitoring would be conducted for multiple years to track any seasonal or interannual variation, as well as changes as the SCH pond complex develops from first wetting of ponds to a more mature aquatic ecosystem.

Selenium in Bird Eggs

Monitoring selenium in bird eggs is the best indicator of potential selenium hazard for several reasons, as reviewed by Ohlendorf and Heinz (2011). First, birds are a principal management target for the SCH Project. As tertiary consumers of fish and invertebrates, they also integrate the selenium pathways and bioaccumulation into a high trophic level receptor. Furthermore, it is selenium in the egg, rather than the parent bird, that causes developmental abnormalities and death of embryos. Bird eggs best represent current contamination in the local environment, given the rapid accumulation (about 2 weeks) and loss (about 10 days) of selenium in eggs from adult females fed selenium-laden food days or weeks before egg-laying. Finally, eggs are easier to collect than adults and the loss of one egg from a nest probably has minimal effect on a population.

Bird eggs would be collected from representative SCH ponds and egg selenium concentration measured. Black-necked stilt is a logical choice for the monitoring, given existing comparable data from nearby and many other sites.

Selenium in Aquatic Biota

Monitoring selenium in aquatic invertebrates and fish would also be useful to better understand bioaccumulation and trophic transfer. Invertebrates and fish would be collected from representative SCH ponds and the sedimentation basin for selenium testing. Fish species would include tilapia, the largest and most important prey for many piscivorous birds, and salifin mollies, a smaller prey fish. Sailfin mollies are also good ecological surrogates for monitoring selenium concentrations in desert pupfish because of similar trophic characteristics (Saiki et al. 2011).

I.5.2 Suggestions for Future Study

Recent studies have improved understanding of selenium bioaccumulation, impacts, minimization, and treatment. At the Salton Sea, focused studies conducted as part of the SCH Project's development have reduced uncertainty about the amount of selenium in the environment at alternative SCH sites (Arnhem and Smith 2010; Amrhein et al. 2011), ecological risk potential for bioaccumulation in the food web (Sickman et al. 2011), and options for removing selenium from water using wetland vegetation (personal communication, N. Terry 2011). Nevertheless, data gaps remain (Sickman et al. 2011). This section identifies some topics for further study, both independently and in association with the SCH ponds once implemented. However, as noted above, these potential studies are not currently part of the SCH Project.

Food-Web Transfer Relationships

Several topics have been suggested by others for further investigation of selenium bioaccumulation (Miles et al. 2009; Sickman et al. 2011). For example, selenium speciation in water and particulates would be useful to establish appropriate coefficients of bioaccumulation, especially K_d factors. Study of stable isotopes (^{34}S, ^{15}N, ^{13}C) would improve understanding of food-web structure and contributions from different prey, which would improve the TTFs used to estimate selenium bioaccumulation in the ecological risk model. Isotopes could also identify spatially explicit sources of contaminant exposure. Selection of target piscivorous birds for use in the SCH ecological risk model should be revisited. Black skimmers would likely be more representative of SCH pond users than others that were considered. In contrast, gull-billed terns feed off site from drains and have a more varied diet than simply fish, while black-crowned night herons would likely be only occasional users of the SCH ponds. Finally, better understanding of local-scale movements and local foraging ecology of birds using the SCH ponds could be important to determine how much of their diet is coming from SCH ponds, and how much is coming from the surrounding areas.

Effects of Residence Time in Ponds

The potential effect of retention time in the ponds on selenium deposition or removal is not well understood (Johnson et al. 2009) and subject to varying opinions among experts (personal communications, H. Ohlendorf and R. Gersberg 2010). On the one hand, shorter retention time in the ponds (i.e., increased rate of flow) could result in increased loading of selenium to the SCH ponds from river water. On the other hand, prolonged retention time could facilitate transformation of selenium into more bioavailable forms. Monitoring of the SCH ponds under varying operational scenarios would help address this question, which has ramifications for costs of long-term operations due to water pumping rates.

Selenium Treatment Technologies

As the Salton Sea progressively becomes more saline, water treatment to remove selenium may become necessary as more river water is used to maintain suitable salinities for the fish community. As discussed above, more information about performance and feasibility of biological treatment techniques would be required to determine whether they would be an appropriate selenium control measure at a future phase of SCH Project implementation. Studies underway by UCB (N. Terry, unpublished data) would refine understanding of constructed treatment wetlands. Other treatment alternatives (reviewed by Cardno ENTRIX 2010, CH2M Hill 2010) also may receive further consideration.

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